FIThydro

Bragado

Vila Pouca de Aguiar – Portugal

Table of Contents

List of figures

FIThydro

List of tables

FIThydro

1. Description of the test case

1.1. Description of the water bodies related to the HPP

The Bragado Hydropower Plant (HPP) is located in the North of Portugal in the Avelames River (water body PT03DOU0211, *sensu* Water Framework Directive, WFD), which is a tributary of the Tâmega River (Douro river basin) (Figure 1).

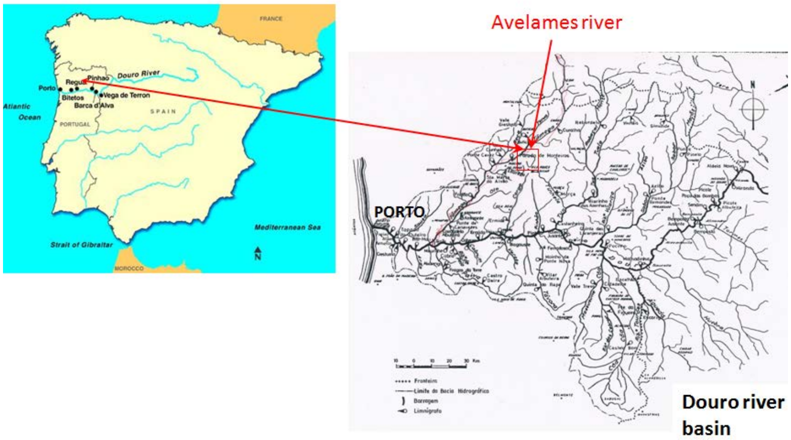

Figure 1 – Location of Avelames River in the North of Portugal.

The segment of the Tâmega River where the Avelames River flows into is the water body PT03DOU0226NA (Figure 2).

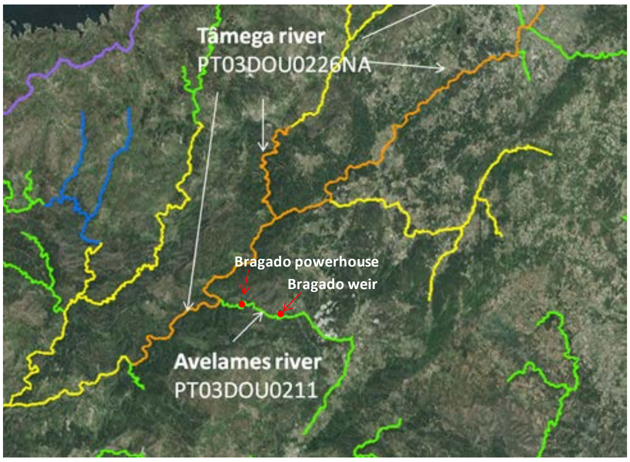

Figure 2 - Summary of additional information regarding status of implementation of the WFD. Green color - water body in good ecological state; yellow color - water body in moderate ecological state; orange color - water body in poor ecological state; blue color - water body in high ecological state.

1.1.1. Hydrology of the Avelames River

Avelames River has a pluvial run-off regime, characterized by a strong seasonal variation in flow, with the highest discharge occurring during the wet semester (October-March). Inter-annual variation in discharge is also large, as it is typical of a river with Mediterranean flow regime. Long term mean annual discharge at Bragado weir amounts to 1.4 m^3/s (watershed area of 78.8 km^2 and a mean annual flow volume of 44.1 hm^3).

The mean monthly flow downstream Bragado HPP is shown at Figure 3.

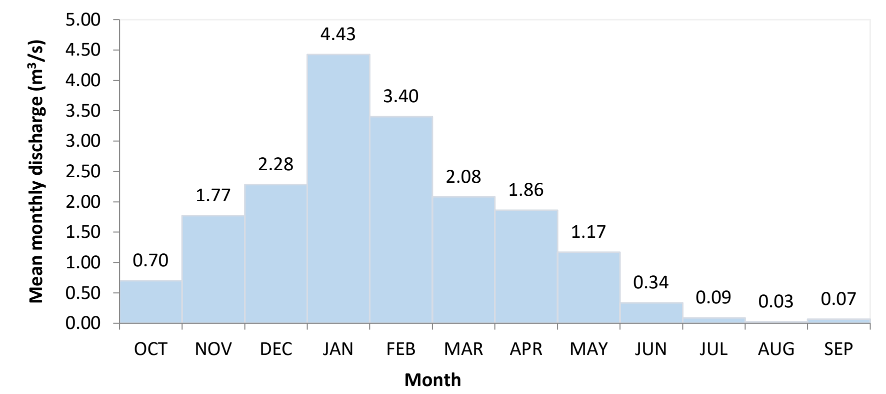

Figure 3 - Mean monthly discharge downstream Bragado HPP (2010-2016)

1.1.1. Main pressures

The water quality at the Avelames River is influenced by discharges from wastewater treatment facilities as well as from agriculture and animal husbandry (Table 1). According to the River Basin Management Plan, the natural water body PT03DOU0211 has Good Ecological State (Figure 2), although the presence and operation of the Bragado HPP have been identified as pressures.

Table 1 - Pressures on the Avelames River according to the Douro River Basin Management Plan (2016-2021)

Qualitative pressures (kg/year)	BOD5 load (9294, mostly generated by the urban wastewater treatment facilities), COD load (37601, mostly generated by the urban wastewater treatment facilities); Total N (47943, mostly generated by agriculture and animal husbandry); Total P (5213, mostly generated by agriculture and the urban wastewater treatment facilities)
Hydromorphological	Presence and operation of the Bragado HPP

The Douro River Basin Management Plan (2016-2021) identifies the following measures for the Avelames River (Table 2):

Table 2 - Measures to be implemented in the Avelames River

Flow change	Ecological flow in bypassed reach since the beginning of the Bragado HPP operation (1998): 0.064 m^3/s
Pollution control	Measures for pollution control include the supervision of the application of a code of good practices to agriculture aimed at reducing diffuse pollution (in 2015 the implementation of this measure was not yet completed).

1.2. Presentation of the HPP

1.2.1 Location of the HPP

Operator

Table 3: Operator information

Company	Hidroerg, Projectos Energéticos, Lda.
VAT number	PT 502166886
Head manager	Pedro Eira Leitão
Adress	Rua dos Lusíadas, n.º 9, 4.º Dto. 1300-365 Lisboa, Portugal

The Bragado HPP is placed in a rural area that is dominated by shrub and forested areas. The small parish of Bragado (544 inhabitants in 2011) is the nearest village (approx. 700 m from the weir). The scheme is located southwest of Bragado village (Figure 4).

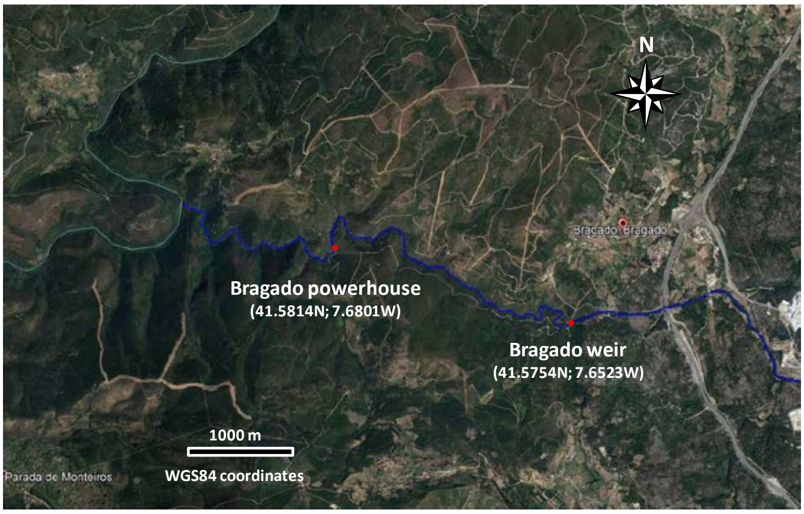

Figure 4 – Location of Bragado HPP and Bragado weir

Bragado is a run-of-river HPP with partial daily flow regulation. It has an installed capacity of 3.1 MW and a mean annual electricity production of 9.0 GWh. The small reservoir created by the weir is equipped with a submerged water intake and has a useful storage capacity of 25000 m^3 (total capacity of 34000 m^3), located between the full reservoir level, FRL=495.1, and minimum drawdown level, MDDL=492.8 (Figure 5). The area of the water surface for the FRL is 5600 m^2. The weir was designed for the 100-year peak flood discharge of 230 m^3/s.

The powerhouse of Bragado was designed for a maximum turbined discharge (or design discharge) of 2.2 m^3/s and a net head of 155.2 m, and it is equipped with one Francis turbine with horizontal shaft.

Downstream the water intake there is the conveyance system which includes an open canal (2490 m long), a forebay, a penstock (900 mm of diameter and 290 m long) and a powerhouse (installed capacity of 3.1 MW) (Figure 5). The bypassed reach of the Avelames River, comprehended between the weir and the tailrace of Bragado powerhouse, is 3.7 km long.

The main characteristics of Bragado HPP are described below at Table 3.

Table 4 - Main characteristics of Bragado HPP

	Avelames (Douro river basin)
Location	Vila Pouca de Aguiar
Long term mean discharge	1.4 m^3/s
Low-water flow	0 m^3/s
Minimum instream flow	0.064 m^3/s
Function of the dam	Hydropower
Length of canal	2 490 m
Length of bypassed reach	~ 3 700 m
Maximum turbine discharge	2.2 m^3/s
Species concerned	Iberian chub (*Squalius carolitertii*), Iberian nase (*Pseudochondrostoma duriense*) and calandino (*Squalius alburnoides*)

The water permit of Bragado HPP was issued in 1996, the construction of the scheme started in August 1997 and the first connection to the national electricity grid took place in December 1998.

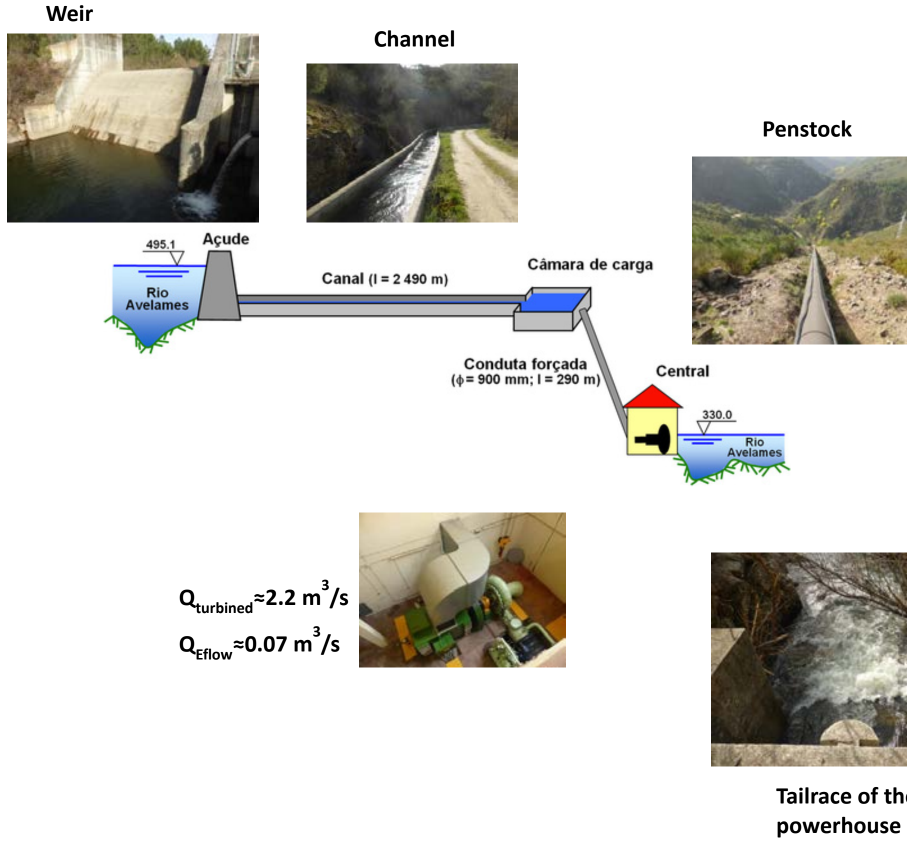

Figure 5 - Bragado HPP scheme

The main characteristics of the Francis turbine installed at Bragado HPP powerhouse are:

- Maximum turbine discharge: 2.2 m^3/s
- Rated head: 155 m
- Number of blades: 14
- Wheel diameter: 0.60 m
- Rotation speed: 1000 rpm

1.2.1. Eflow

The minimum instream flow/ecological flow (Eflow) to be released downstream Bragado weir (Figure 6) was fixed as a percentage of the mean annual flow (5%), which was a common procedure by the time the HPP was licensed. If the natural flow is lower than the Eflow (64 l/s), all the inflow is automatically released downstream and the powerhouse does not operate. For higher inflows, the difference between each inflow and the Eflow is conveyed by the hydraulic circuit until its design discharge (2.2 m^3/s). The discharges exceeding 2.2 m^3/s are spilled over the weir.

The efficiency of the ecological flow, regarding the environmental objectives set in the Water Framework Directive, has never been assessed; however, the water body were the HPP is located presents a good ecological state.

Figure 6 – At the left bank, ecological flow release at the Bragado weir

1.2.2. Upstream or downstream migration devices

The Bragado weir does not have a fish pass for either upstream or downstream fish migration. Such device was considered unnecessary by the Portuguese authorities since the HPP is located in a reach of the Avelames River with reduced natural connectivity, due to natural falls. Further, migratory fish species requiring long distance movements to reproduce do not occur in this river.

The submerged water intake is protected by a movable vertical trash rack with 1.5 x 2.4 m^2 (clear space between bars of 5 cm).

1.2.3. Hydropeaking

The rapid discharge variations during intermittent electricity production (hydropeaking effect) can affect negatively the fish species, namely because such intermittent operation occurs during periods when the natural discharge is normally very low (late spring and summer). Hydropeaking can promote the occurrence of depauperated fish assemblages in terms of the species and size-classes. However, its consequences in Iberian streams, where fish assemblages are composed mainly by endemic species, are still relatively unknown.

2. Objectives for this test case

What are we planning?

The following activities are planned for Bragado HPP:

- Assessment of fish assemblage composition along the Tâmega River basin.
- Analysis of river discharges, habitat and fish populations in distinct river reaches: i) upstream the Bragado reservoir (natural section, i.e. unaffected by the hydropeaking) and downstream the tailrace of the powerhouse (section affected by hydropeaking).
- Comparison of the river regime, the habitat and the fish assemblages/populations/between different sites/seasons.
- Assessment of fish behaviour (movement and habitat use).
- Field implementation of selected SMDT and evaluation of their results.

Why are we planning this on this test case?

Information about the effects of hydropeaking in Iberian small streams is relatively scarce. Consequently, the research planned for Bragado HPP aims at contributing to increase the knowledge about that topic.

In the Bragado HPP the following (scientific) research tasks are planned:

- Assessment of the factors likely responsible for shaping the composition of fish assemblages in the Tâmega River basin.
- Assessment of the hydropeaking effects by comparing the river regime, the habitat and the fish populations/assemblages between different sites and seasons.
- The previous assessment will include a comparative assessment of fish behaviour (movement and habitat use).
- Evaluation, through habitat modelling, the effects of peak flows on habitat availability.
- Possible field implementation of SMDT selected and evaluation of their results.

What are we expecting?

We expect to increase the knowledge about the effects of hydropeaking in small Iberian streams and to identify appropriate solutions capable of reducing/mitigating such effects.

Relevance in FIThydro?

Besides its innovative contribution about the effects of hydropeaking phenomena in an Iberian river, the study to be conducted at Bragado HPP aims to meet some of the objectives within the FIThydro project, including the evaluation of SMTDs aiming at reducing the impacts of hydropeaking on endangered small sized endemic cyprinids.

FIThydro

3. Presentation and results of activities in FIThydro.

3.1. Fish community of the Tâmega River basin

3.1.1. Introduction

The Iberian fish fauna has a high level of endemism, occupying a unique position in the European ichthyofauna (Doadrio 2001; Reyjol *et al.* 2007). The specificity of the Iberian ichthyofauna is highlighted in a number of studies, namely in the typologies developed within the European FAME project (FAME Project - Development, Evaluation and Implementation of a Standardized Fish-based Assessment Method for the Ecological Status of European Rivers: http://fame.boku.ac.at), where the river basins of the Iberian Peninsula clearly stood out from the other European river basins.

To frame the research conducted in the Bragado HPP, a short review of the available information on the fish assemblages of the Tâmega River basin was conducted. The review aims to establish the fish fauna of the river basin and the major factors likely responsible for shaping the composition of fish assemblages in this Douro River sub-basin (Table 4).

Table 5 - Basin area for the Tâmega and Avelames River basins. Including the Spanish part of the basin

River basin	Area (km^2)
Douro/Duero	98370
Tâmega	3231
Avelames	93

3.1.2. Methodology

The fish assemblages of the Tâmega River basin were studied during the last 20 years (including research studies, environmental impact assessments and monitoring studies) (e.g. Cortes *et al.* 1990; Rodriguez-Ruiz & Granado-Lorencio 1992; Ferreira *et al.* 2000; INAG 2001; Madeira 2002; Filipe 2004; Oliveira *et al.* 2007; Godinho unpublished results). From those studies, data on fish species presence-absence in electrofishing surveys were gathered for 55 fluvial reaches (Figure 7) and used to prepare a matrix (sampling reaches x species occurrence). The fish occurrence data were examined to assess global taxa distribution throughout the basin and were subjected to Principal Component Analysis (PCA) to highlight major assemblage patterns. Species occurring in less than 10% of the fish surveys were not considered to prevent analysis distortion (Godinho *et al.* 2014). PCA was run using STATISTICA (StatSoft 2000).

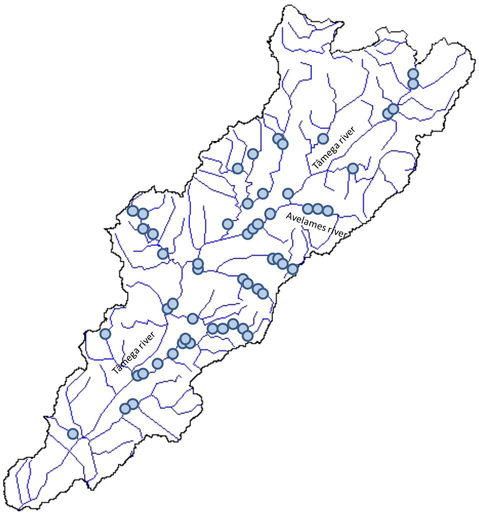

Figure 7 - Places with fish assemblage data in the Tâmega River basin (presence-absence, depicted by a blue circle).

3.1.3. Results

In the Tâmega River basin, 18 fish species have been collected in electrofishing surveys, including 55.6% introduced taxa and six Iberian endemism (Table 5). Nevertheless, most introduced species are still restricted to the Tâmega River itself or to the terminal part of some tributaries. The number of species varied from 1 to a maximum of 9 per sampling reach (average richness ± SD = 3.24 ± 2.00). Species richness was higher in the Tâmega River (5.73 ± 1.95) than in its tributaries (2.61 ± 1.47).

The Tâmega River basin includes some of the endangered biological units in Europe, presenting three species listed in Annex II of the Community Directive 97/62/EC (animal and plant species of Community interest whose conservation is designated as special areas of conservation). According to the Portuguese Red Book (Cabral *et al.* 2005), two of the species present in the basin have a threat status.

Most common species in the basin (occurring at least in 20% of the sampling reaches) included the following: Iberian barbel (*Luciobarbus bocagei*), Iberian nase (*Pseudochondrostoma duriense*), Iberian chub (*Squalius carolitertii*), brown trout (*Salmo trutta fario*) and pumpkinseed sunfish (*Lepomis gibbosus*) (Figure 8, 9, 10, 11, and 12).

Table 6 - Fish taxa occurring in the Tâmega River basin.

Taxa	**Common name**	**Conservation status**		
		Portuguese Red List of threatened species	Directive 97/62/CE	IUCN Red List of threatened species
Anguillidae				
Anguilla anguilla	European eel	Endangered	Not evaluated	Critically endangered
Cyprinidae				
Achondrostoma oligolepis	Iberian curved mouth nase	Least concern	Anexo II	Not evaluated
Alburnus alburnus	ablete	introduced		
Carassius auratus	crucian carp			
Cyprinus carpio	common carp			

Gobio lozanoi	Iberian gudgeon			
Luciobarbus bocagei	Iberian barbel	Least concern	Anexo V	Least concern
Pseudochondrostoma duriense	Duero nase	Least concern	Anexo II	Vulnerable
Squalius alburnoides	Calandino	Vulnerable	Anexo II	Vulnerable
Squalius carolitertii	Iberian chub	Least concern	Not evaluated	Least concern
Cobitidae				
Cobitis paludica	Iberian loach	translocated		
Salmonidae				
Oncorhynchus mykiss	rainbow trout	introduced		
Salmo trutta	brown trout	Least concern	Not evaluated	Least concern
Atherinidae				
Atherina boyeri	sand smelt	Data deficient	Not evaluated	Least concern
Poeciliidae				
Gambusia holbrooki	mosquitofish	introduced		
Centrarchidae				
Lepomis gibbosus	pumpkinseed sunfish	introduced		
Micropterus salmoides	largemouth bass			
Percidae				
Sander lucioperca	pikeperch	introduced		

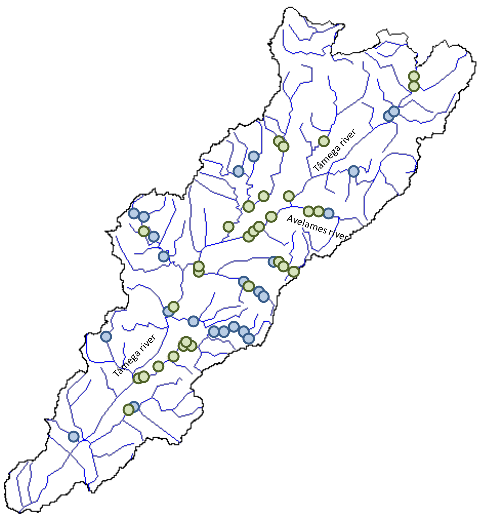

Figure 8 - Distribution of *Pseudochondrostoma duriense* in the Tâmega River basin. Sampling site with species presence is denoted by a green circle, whereas sampling sites with absence are denoted by a blue circle. The species occur in the Avelames River.

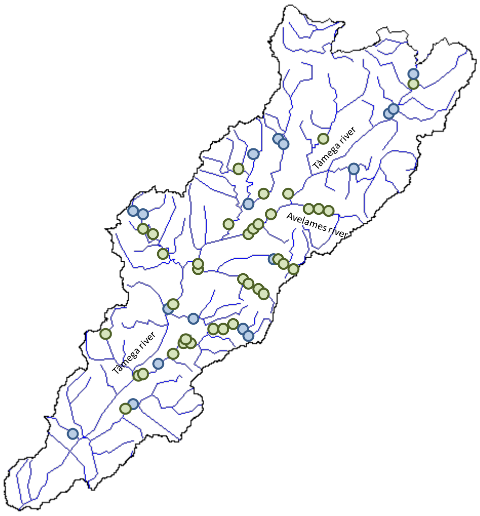

Figure 9 - Distribution of ***Squalius carolitertii*** in the Tâmega River basin. Sampling site with species presence is denoted by a green circle, whereas sampling sites with absence are denoted by a blue circle. The species occur in the Avelames River.

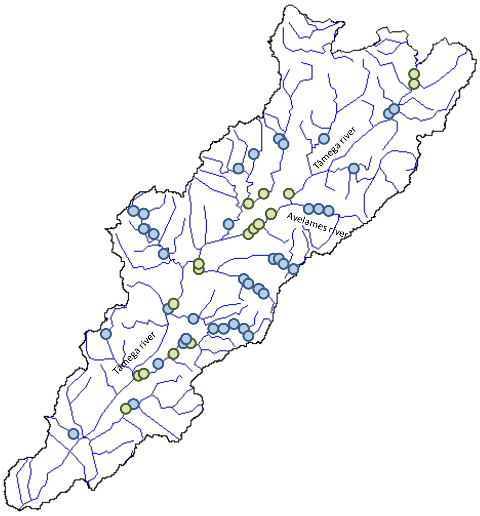

Figure 10 - Distribution of ***Luciobarbus bocagei*** in the Tâmega River basin. Sampling site with species presence is denoted by a green circle, whereas sampling sites with absence are denoted by a blue circle.

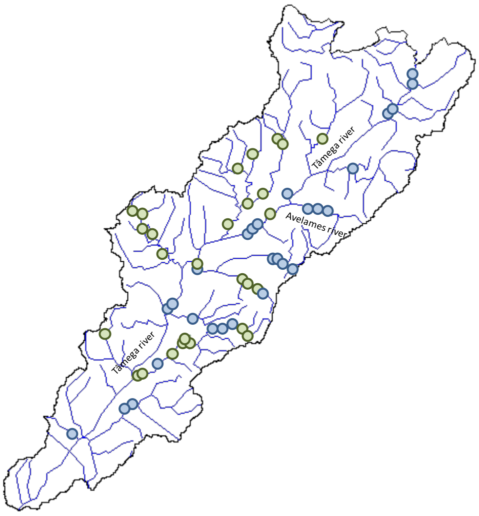

Figure 11 - Distribution of *Salmo trutta fario* in the Tâmega River basin. Sampling site with species presence is denoted by a green circle, whereas sampling sites with absence are denoted by a blue circle.

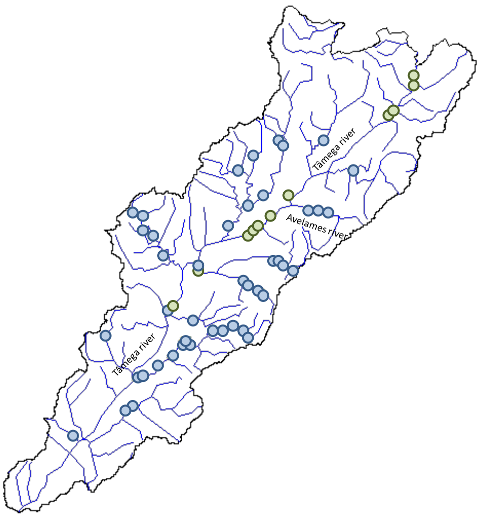

Figure 12 - Distribution of *Lepomis gibbosus* in the Tâmega River basin. Sampling site with species presence is denoted by a green circle, whereas sampling sites with absence are denoted by a blue circle.

Iberian chub was the most common species in the electrofishing surveys, occurring in 67% of the reaches, followed by the Iberian nase (present in 56% of the surveys) and brown trout (present in 49% of the surveys).

The first two factors of the PCA performed accounted for 58.8% of the variation in fish assemblage composition (Figure 13). Overall, a general gradient in fish species occurrence was depicted from the Tâmega River to its tributaries. Brown trout, being present mostly in tributaries, was separated from the remaining species, particularly the eel and pumpkinseed sunfish that occurred only in the Tâmega River. The Gudgeon (*Gobio lozanoi*) and the barbel occurred mostly in the main river and at larger tributaries, whereas the other native cyprinids (chub, nase, calandino and *A. oligolepis*) occurred both in the main river and tributaries, being frequently associated to the same sampling reach.

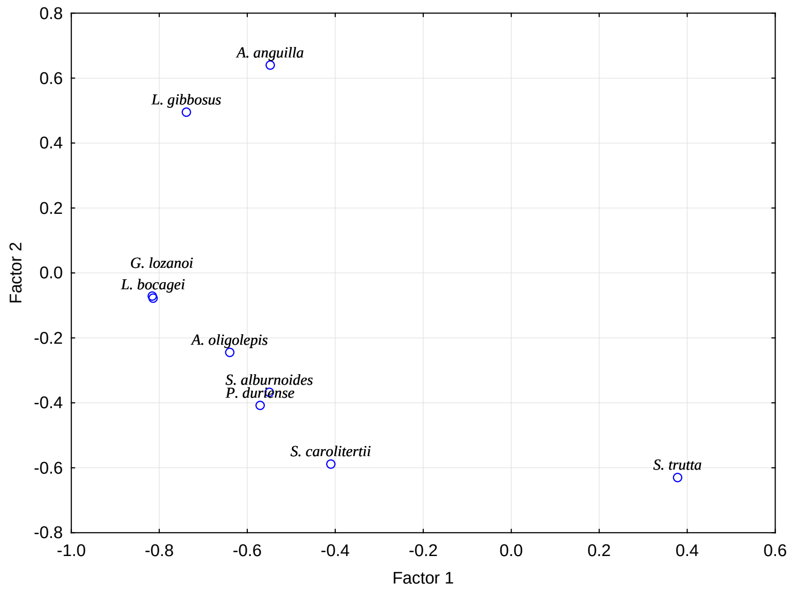

Figure 13 - Factor 1 and 2 of the PCA performed on the matrix of presence-absence of fish species in 55 electrofishing surveys made throughout the Tâmega River basin. Eigenvalues were 3.52 and 1.77, respectively, for the first and second factor.

3.1.4. Discussion

The Tâmega River basin presents a native fish community characterized by brown trout and several endemic cyprinids. The species richness increase from tributaries to the main river, although ~~some~~ a part of this increase was related to the presence of introduced species.

The fish community presents a pattern of variation along the basin that is somewhat similar to that observed in other Northern Portuguese basins, with the increase in the presence of trout and the decrease in the presence of cyprinids as we progress towards headwaters (e.g. Godinho *et al.* 1998; Ferreira *et al.* 2000; Santos *et al.* 2004). Elsewhere, this fish zonation is related to environmental variables such as water temperature and dissolved oxygen, with warmer temperatures in the lowland main rivers preventing the presence of trout. In addition to this global variation, other patterns are also evident from the data, such as the predominance of the larger sized barbel in the main river, whereas the other, smaller cyprinids, can also occur in small streams.

The fish community of the Avelames River sampled in 1996 before the construction of the Bragado HPP, showed assemblages composed exclusively of native cyprinids. In accordance with the Avelames River characteristics, the fish assemblages do not include either trout or the larger sized barbel, being dominated by chub and nase.

3.2. Fish and habitat analysis

3.2.1. Methodology

To analyse the habitat and the fish population at Bragado HPP two river reaches were initially selected in the Avelames River, one upstream the Bragado weir (hereafter upstream) (41º34'34.95''N, 7º38'51.37''W, *c.* 502 m a.s.l.), and another downstream the tailrace of Bragado powerhouse (hereafter downstream) (41º34'53.27''N, 7º40'50.95''W, *c.* 337 m a.s.l.). Both river reaches length ~~is~~ are *c.* 150 m. The two reaches were considered to allow a broader analysis of the aquatic habitat modifications due to the presence of the HPP.

The upstream river reach would act as the reference because it is not affected by hydropeaking. However, due to the existence of a quarry that was releasing polluted water into the river; we did not consider the upstream river reach with respect to direct comparisons with the downstream river reach. Also, the results concerning the fish community were not promising with a low number of individuals and species found at different sampling campaigns.

The river bed topography was surveyed at both reaches to allow the modelling for different discharges. The river reach downstream Bragado powerhouse will be modelled with a 2D and a 3D model to assess the fish mesohabitats.

Because Avelames River is an ungauged watershed, to obtain a reliable forecast of the discharges under natural conditions along the river reach were Bragado HPP is installed a regionalization model for mainland Portugal (Portela 2014) was applied, based on the following equation:

$$Q_2 = Q_1 \times Qmod_2 \div Qmod_1$$ **Equation 1**

where *Q* refers to a daily/subdaily discharge (m^3/s) and *Qmod* is the long term mean annual discharge (m^3/s). Index 1 relates to a gauged watershed with discharge records and index 2 to an ungauged watershed. In the applications accomplished, different ungauged watersheds were considered along Avelames River. Furthermore, a computational simulation algorithm approach was applied to simulate the Bragado HPP operation scheme and to assess the flows downstream the tailrace of the powerhouse at a daily and subdaily scales.

To characterize the local fish assemblages, a survey by means of electrofishing was done at both river reaches. Fishes were captured in the upstream and downstream river reaches of Avelames River by electrofishing over the entire reach, using an electrofishing gear (Hans Grassl IG-200), according to European norms - CEN EN 14011:2003, Water quality - Sampling of fish with electricity (European Committee for Standardization–CEN [CEN 2003]) and national guidelines (INAG 2008). After electrofishing fish were sorted by species, measured for total length (TL), weighted for total weight (TW) and released at the local of collection.

FIThydro

3.2.2. Results

3.2.2.1. Hydrology

The mean daily discharges used to establish the natural regime for the Avelames River were obtained at Santa Marta do Alvão gauging station (watershed area of 48.8 km^2), located at Louredo River, also belonging to Tâmega River watershed. Because Louredo and Avelames River present similar morphological characteristics and mean annual flow depths we could apply the regionalization/transposition procedure from the gauging station to the HPP.

Based on the regionalization procedure, two discharge series under natural conditions were obtained: one at the section of the weir of the Bragado HPP and another for the intermediate watershed between the weir and the powerhouse sections (watershed areas of 78.8 and 6.2 km^2, respectively). Because the discharge series refer to daily discharges, in order to have subdaily discharges, a constant value was considered along each day.

The simulation model for the daily operation of the HPP considered the mass balance equation (Equation 2) provided that the volume of water stored in the reservoir does not exceeds its capacity (Equation 3), according to:

$$Va - Ve - L = \Delta S \qquad \textbf{Equation 2}$$

$$S \leq C \qquad \textbf{Equation 3}$$

where *Va* is the inflow volume at the section of the weir , *Ve* is the outflow volume (i.e. the turbined flow, the Eflow, and the water spilled over the weir), *L* are the infiltration/evaporation losses volume, Δ*S* is the change of the volume stored in the reservoir and *C* is the reservoir capacity.

According to the Bragado HPP operation, once the Eflow is released, discharges over the weir occur whenever the inflow exceeds the scheme design discharge and the available storage capacity is not enough the store the excess inflow volume.

To analyse the hydropeaking, the study adopted as key section a cross section located downstream the powerhouse tailrace, as represented in Figure 7. The discharge (and therefore the respective flow volume) at that section is given by the sum of the following parcels: Eflow, hypothetical discharges over the weir, turbined discharge, and contribution of the intermediate watershed (6.2 km^2), between the weir and the tailrace of the HPP.

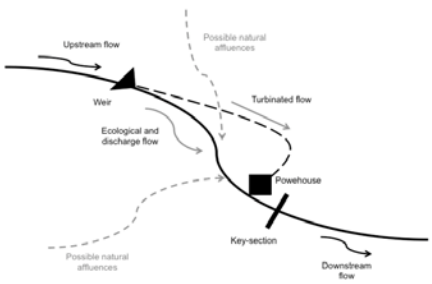

Figure 14 – Bragado HPP scheme. Localization of the weir, HPP and key-section.

The algorithm to simulate the daily operation of Bragado HPP was validated by comparing the computed turbined flows and the energy production with the corresponding real values. The energy produced was calculated based on the estimates of the turbined volumes, according to Equation 4.

$$E = V_{turb} \times H_d / (\frac{3600}{9.8\eta})$$ **Equation 4**

where, for a given time interval, *E* is the energy (GWh); V_{turb} is the turbined volume (hm^3); H_d is the design net head (m) and η is a global efficiency of the HPP.

The comparison between the mean monthly values of the simulated and measured turbined discharges is shown at Figure 15.

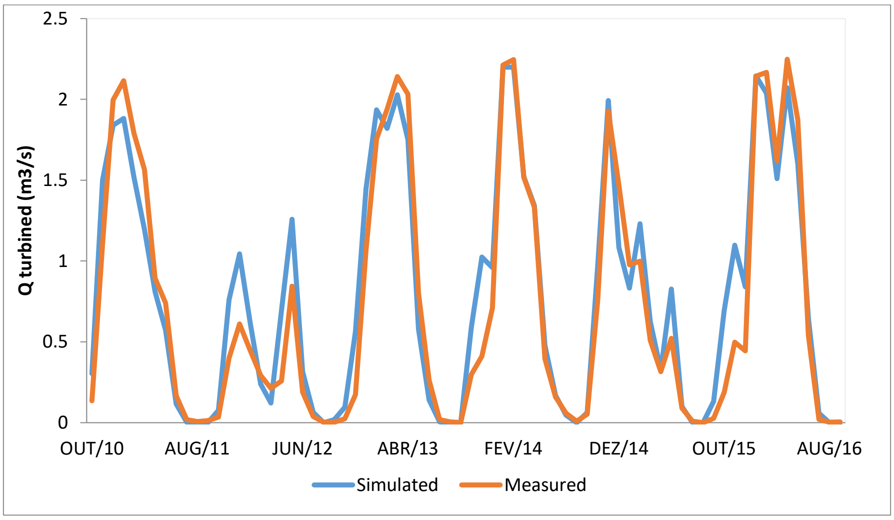

Figure 15 - Mean monthly real and simulated turbined flows during 20010/11 until 2015/16.

The previous figure shows that the computed and registered mean monthly discharges agree quite well. It should be noted that, for simplicity, the simulation algorithm did not consider the concentration of energy production out of the empty hours.

Considering the simulation model, the contributions to the downstream river reach are showed at Figure 16.

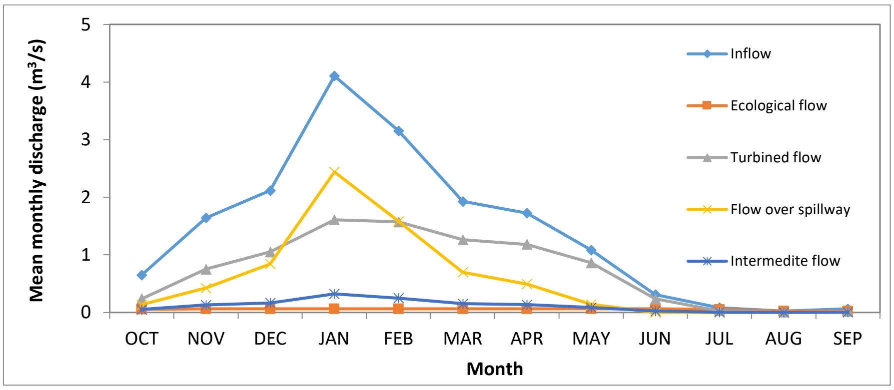

Figure 16 – Mean monthly flows at Bragado HPP scheme.

Along the hydrologic year the turbined flow follows the inflow pattern, using as much water as possible in order to maximize revenues. Only when the inflow exceeds the ecological flow plus the design discharge of Bragado HPP then the water is released over the spillway, if the reservoir is at its full capacity. If not, the water is stored in the reservoir.

3.2.2.2. Fish populations

The fish assemblage community of the Avelames River is dominated by small sized native cyprinids, as it is typical of similar rivers in northern Portugal. Further downstream, close to the confluence with the Tâmega River, other species can be found, including the larger sized Iberian barbel (*Luciobarbus bocagei*). Further upstream some brown trout (*Salmo trutta*) can be found (see Chapter 3.1).

To assess the fish assemblage composition in the vicinity of the Bragado HPP before the beginning of the study, in December 2017, an electrofishing ~~-~~fish survey took place at the two sampling reaches (upstream and downstream Bragado HPP, Figure 10).

Figure 17 – Fish survey at Bragado ; a) upstream Bragado weir ; b) downstream Bragado HPP

A pool of three cyprinid species - Iberian chub (*Squalius ~~pyrenaicus~~carolitertii*), the calandino (*Squalius alburnoides*) and the Iberian nase (*Pseudochondrostoma ~~almacai~~duriense*) - were found at both sites. Chub and nase were the predominant species, as expected given the patterns of fish assemblage variation in the Tâmega River basin (see Chapter 3.1). A few specimens of the European eel (*Anguilla*

anguilla) were also found at the downstream river reach, but were not measured or weighted. A summary of the survey data is shown at Table 4.

Table 7 – Fish survey at river reach upstream Bragado weir and downstream Bragado HPP

River reach	Fish species	N	Total weight (g)	Total length (cm)
Upstream Bragado weir	*Squalius alburnoides*	2	1.0±0.0	7.1±0.1
	Pseudochondrostoma duriense	1	1	4.1
	Squalius ~~pyrenaicus~~carolitertii	8	36.6±30	13.7±5.0
Downstream Bragado HPP	*Squalius alburnoides*	1	7.5	3.0
	Pseudochondrostoma duriense	94	4.2±4.3	7.9±2.0
	Squalius ~~pyrenaicus~~carolitertii	8	7.8±7.3	8.6±2.6

*Average values ± standard deviation

The low number of individuals caught upstream Bragado HPP was probably related to the low water level and to the negative influence of a quarry that was releasing polluted water into the river.

3.2.2.3. Habitat analysis

To characterize the habitat downstream and upstream Bragado HPP we have chosen a two-dimensional approach. The river bed topography was surveyed in September 2017 using a combination of a Nikon DTM330 total station and a Global Positioning System (GPS) (Ashtech, model Pro Mark2) (Figure 18). Trees, boulders, and large objects were defined by marking the object intersection with the river bed and by surveying the points necessary to approximately define its shape. The river bed substrate was also characterized.

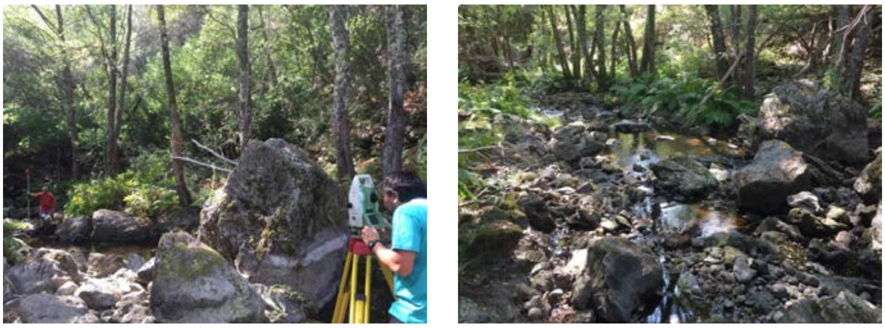

Figure 18 – Topography survey in the river reach downstream Bragado HPP

Altogether, 2506 points were surveyed at the river reach downstream the HPP and 2539 points at the upstream river reach (Figure 19 and Figure 20).

Figure 19 – River bed topography at the upstream river reach.

Bypass

Bragado HPP
Water release

Key-section

Figure 20 - River bed topography at the downstream river reach.

The upstream river reach did not meet the reference conditions from which it would be compared with the disturbed river reach, *i.e.* the downstream river reach. Therefore, we opted for not surveying and modelling the upstream reach.

3.3. Hydropeaking

3.3.1. Methodology

3.3.1.1. Characterization of hydropeaking

To characterize the Bragado HPP operation mode we applied the COSH tool, developed by Sauterleute & Charmasson (2014), to a 15 min interval flow series to identify and quantify rapid fluctuation in flow and water level with a subdaily resolution. The COSH tool allows to separate the peak events in rapid increases corresponding to upramping and rapid decreases of flow corresponding to the downramping. After detecting the peak events, the COSH tool identifies multiple peaking events, as a result of a successive starting and stopping of the turbines in a HPP. Additionally, the COSH tool also identifies peak events according to daylight conditions (daylight, darkness and twilight), because daylight strongly influences fish behaviour and movements.

To calculate the water level at the key-section, schematically located in Figure 7, a rating curve was calculated. The limits adopted when computing the rating curve vary from 0.01 to 131.6 m^3/s (the highest recorded discharge), with an increment of 0.05 m^3/s. The values assumed for Ks and for the slope of the river bed were 15 $m^{1/3}$/s (slow flow with deep zones and vegetation, Lencastre 1993) and 0.0332 m/m respectively. The rating curve is:

$$Q = 9.94 \times (h - 0.024)^{2.239} \quad \text{Equation 5}$$

where *h* is the flow depth. To quantify hydropeaking impacts we have applied Carolli *et al.* (2015) methodology. This methodology consists of 2 indicators to characterize three different levels of physical alteration caused by hydropeaking. The two indicators are: HP1, a dimensionless measure of the magnitude of hydropeaking and, HP2, which measures the temporal rate of flow changes in m^3/s/h.

The first parameter is defined as:

$$HP1_i = \frac{Q_{máx,i} - Q_{min,i}}{Q_{mean,i}} \; i \,\epsilon\, [1, 365] \quad \text{Equation 6}$$

$$HP1 = median|HP_i| \quad \text{Equation 7}$$

where index *i* denotes the day of the year. HP1 is the annual median of daily discharges of $HP1_i$, calculated as the difference between the maximum and the minimum discharges ($Q_{max,i}$ and $Q_{min,i}$, respectively) over the *i*-th day, divided by the long term mean daily discharge ($Q_{mean,i}$)

The second parameter is defined as:

$$(HP2_k)_i = \left(\frac{\Delta Q_k}{\Delta t_k}\right) = \left(\frac{Q_k - Q_{k-1}}{t_k - t_{k-1}}\right)_i \; i \in [1, 365]$$ **Equation 8**

$$HP2_i = P_{90}|(HP2_k)_i|$$ **Equation 9**

$$HP2 = median|HP2_i|$$ **Equation 10**

where Q_k refers to each subdaily flow of the data series, HP2 is calculated as the annual median of daily values of $HP2_i$ in $m^3/s/h$ and $HP2_i$ is the 90th percentile (P90) of the discretized time derivative of the subdaily flow series.

To classify the level of impact of hydropeaking is necessary to calculate a threshold for each indicator: TR_{HP1} and TR_{HP2} which are defined by:

$$TR_{HP1} = P_{75}(HP1_i^{unp}) + 1{,}5(P_{75} - P_{25})(HP1_i^{unp})$$ **Equation 11**

$$TR_{HP2} = P_{75}(HP2_i^{unp}) + 1{,}5(P_{75} - P_{25})(HP2_i^{unp})$$ **Equation 12**

where $HP1_i^{unp}$ and $HP2_i^{unp}$ are the daily values of the 2 indicators for watercourses in natural regime and P75 and P25 are the 75th and 25th percentile of the distribution, respectively. Classification of the impact level of hydropeaking in watercourses in modified regime is:

- Class 1: non/low impact: $HP1<TR_{HP1}$ and $HP2< TR_{HP2}$
- Class 2a: medium impact: $HP1>TR_{HP1}$ and $HP2<TR_{HP2}$
- Class 2b: medium impact: $HP1<TR_{HP1}$ and $HP2>TR_{HP2}$
- Class 3: high impact: $HP1>TR_{HP1}$ and $HP2>TR_{HP2}$

3.3.1.2. Fish habitat use

To assess fish movements and habitat use downstream Bragado HPP due to hydropeaking, fishes were individually marked with PIT-Tags and tracked with an Oregon RFID portable reader -and pole antenna (Cucherousset *et al.* 2005; Kelly *et al.* 2017) in the downstream river reach. With that aim, fish were captured during daylight ~~in the selected river reach~~ by electrofishing over the entire reach in 16 and 17 of May 2018~~, using a Pulsed DC electrofishing gear (Hans Grassl IG-200), according to European norms - CEN EN 14011:2003, Water quality - Sampling of fish with electricity (European Committee for Standardization–CEN [CEN, 2003]) and national guidelines (INAG, 2008)~~ Figure 17 and Figure 21. After electrofishing, fish were stabilized in a fish corf in the Avelames River for at least 2h. Afterwards, fish were sorted by species, measured for total length (TL) and weighted for total weight (TW).

The abdominal region was disinfected with an iodine solution (betadine) in preparation for tag insertion. Fish measuring >60 mm and weighting more than 5 g were anaesthetized with eugenol before marking. Smaller fish were not marked to guarantee the tag weight is <2% of fish body (Winter 1983; Brown *et al.* 1999). Each fish was marked with a small HDX PIT-Tag (12 x 2.12 mm, weighting 0.1 g from Oregon RFID) previously placed in a pot with ethyl alcohol 96% for sterilization. The tag was injected in the intraperitoneal cavity with a sterilized needle linked to a grip injector (Oregon RFID). One hour following the insertion and after regaining equilibrium, fish were released at their capture location.

Commented [FGodinho1]: informação já referida antes

Detection campaigns were set after marking the fish to cover different seasons (i.e. late spring, late summer). In each campaign, the operator will walk the river upstream in a zigzag pattern, scanning the entire river reach with the portable reader and pole antenna (Kelly *et al.* 2017) looking for tagged fish avoiding flow disturbance. Each time a fish is detected, the fish ID is recorded and water velocity and depth are measured, and the substrate is characterized. The portable Oregon high performance HDX RFID reader, ISO 11784 compatible, and pole antenna used (c. 50 cm in diameter) can have a detection range of approximately 45 cm for the PIT tags used.

Commented [FGodinho2]: verbo no futuro?

Commented [FGodinho3]: was?

3.3.1.3. Macroinvebrate assemblages

The macroinvertebrate community was characterized by collecting samples at the downstream river reach. Drift nets were installed upstream the water release from Bragado HPP (one) and downstream the river reach *c.* 100 m downstream the water release (two). The passive collection of macroinvertebrates present in the water column lasted 2h. Also 2 "kick" samples were collected, one upstream and another downstream the water release, according to the protocol established by the Portuguese Environment Agency to determine the biological water quality. All samples were stored in 70% alcohol.

In the laboratory, all the samples were sorted, in order to separate the detritus and leaf litter from macroinvertebrates. Clean macroinvertebrate samples were stored in 70% alcohol and glycerol (9:1). After sorting, macroinvertebrate samples were identified with the help of a stereomicroscope.

3.3.2. Results

3.3.2.1. Characterization of Hydropeaking

To analyse the rapid fluctuations due to the HPP operation, the COSH-tool was applied to water level (h) series at the key-section (see Figure 7 and Figure 13). For that purpose a time step of 15 min was adopted. Before computing the water levels, all null discharge at the section were replaced by 0.01 m^3/s, because COSH-tool would assume zero as a missing value. After that, a water level was assigned to each discharge, according to the rating curve previously presented (Equation 5). The discharge series is represented in Figure 21.

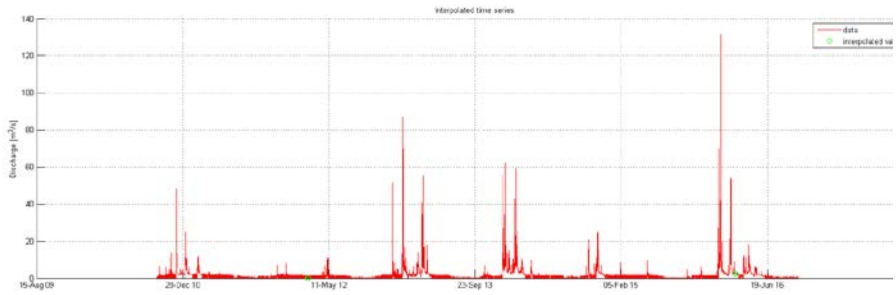

Figure 21 – Flow series from October 1st 2010 to September 30th 2016 at the key-section downstream Bragado HPP.

The highest discharge occurred during a flood in 2016. With exception for the year 2012, all the others present flood events as a result of short intensive precipitation events in a very small watershed, as the one under analysis.

In order to smooth the input discharge data, a moving average (w) with a running length of 5 was applied. To identify the rapid increases and decreases different thresholds were set (Table 7).

Table 8 – Threshold values for analysis of the water level time series for Avelames River

W [-]	Cinc [-]	Cdec [-]	P [-]	T [min]	D [min]
5	0.13	0.13	0.2	120	45

The factors Cinc and Cdec, are usually in the range of 0.05-0.2 and are adjusted to assess the peak events (for more information see Sauterleute & Charmasson (2014)).

After applying the assigned thresholds we have run the COSH-tool for the 6 hydrologic years. The number of rapid increases and decreases per year is represented in Figure 22.

Figure 22 – Number of rapid increases (N_{inc}) and decreases (N_{dec}) per year for the Avelames River downstream Bragado HPP

For the years 2010 and 2016, the data is not complete: in 2010 only data from September to December was available and in 2016 only data from January to September was available. The years with more peaking events were the ones with less water availability, like 2015. Based on data, we could conclude that Avelames River is very sensitive to rapid fluctuation of flow/water level during low flow periods. Hence the difference between turbine and river discharges is very high and COSH-tool detects the peaking events immediately.

Concerning the time between a rapid increase and the start of a rapid decrease (T_{high}) and the time between a rapid decrease and a rapid increase (T_{low}), the results show that T_{high} occurs mostly during the winter and T_{low} during the summer period (Figure 23).

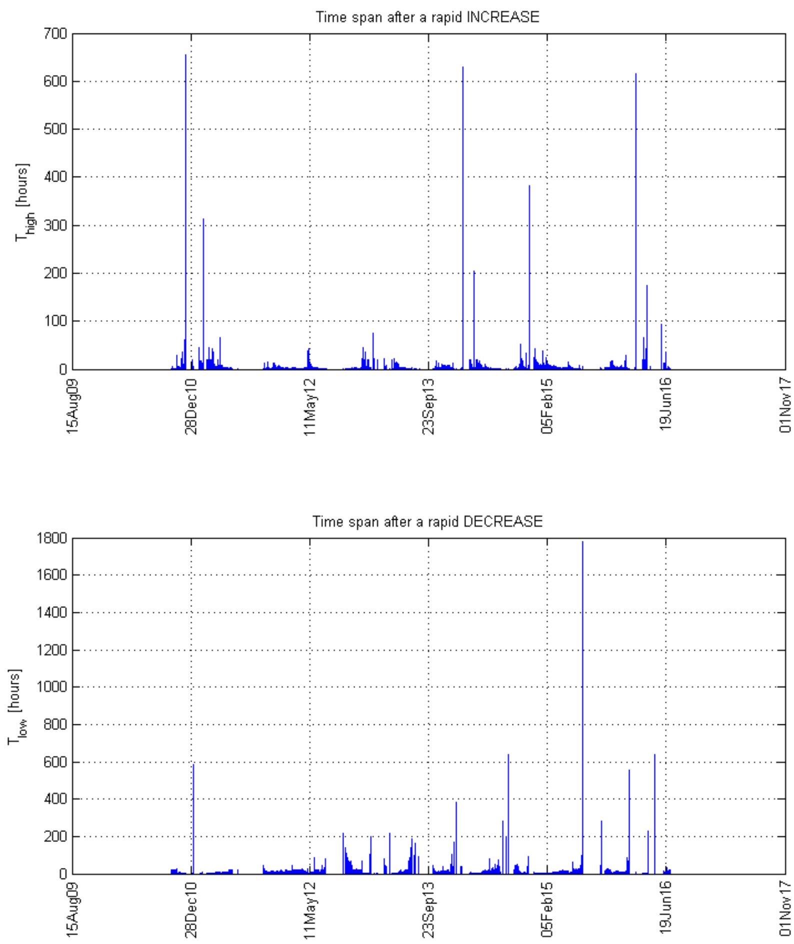

Figure 23 – T_{high} and T_{low} along the 6 years flow series

When analysing the cumulative distribution of the time periods (Figure 24) we verify that 95% of the T_{high} last less than 24h and 50% of the T_{high} last 2h. Thus, in general, Bragado HPP turbines during 2h in continuous. The inflection point of the curve for T_{high} is observed at 17h, where the probability variation becomes asymptotic. For T_{low}, 90% of the events last 20h, while 50% last 5h.

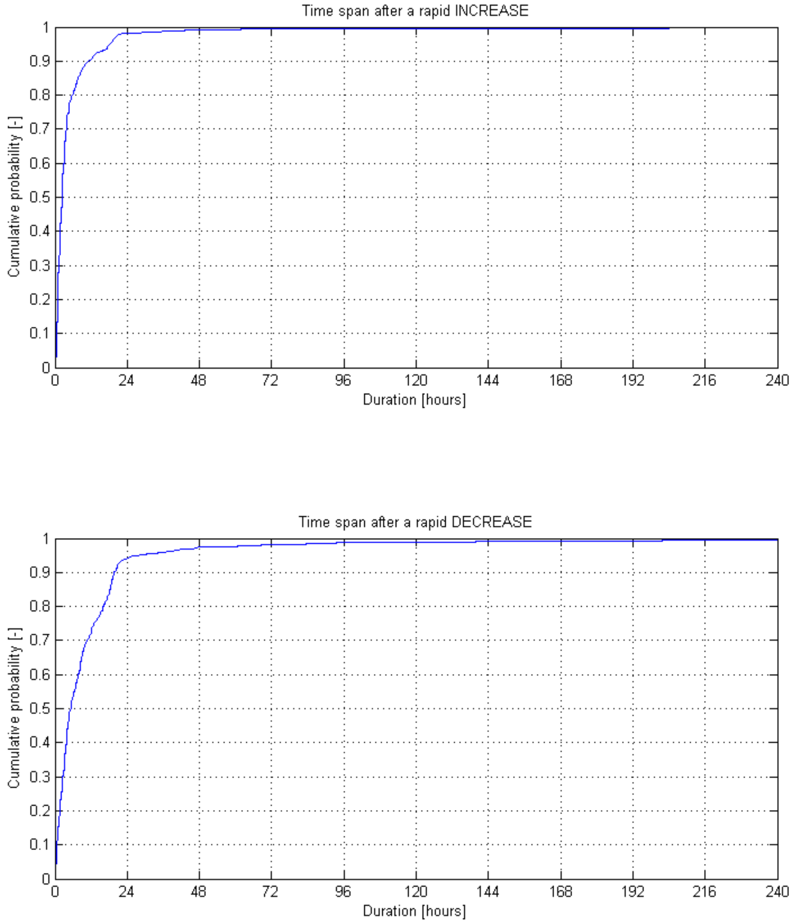

Figure 24 – Cumulative distribution of time span after a rapid increase and after a rapid decrease.

In general, Bragado HPP operates only once a day (Figure 25). Rapid increases and decreases tend to occur in the wet period from October to June. In the summer, the HPP do not operate due to the lack of water (Figure 25).

The operation scheme of Bragado HPP reflects the daily periods regarding the energy tariffs paid to the company. The rapid increase occurs in the morning followed by a rapid decrease around 14h (2 pm), the same pattern occurs at the end of the day c. 18h (6pm) (Figure 26).

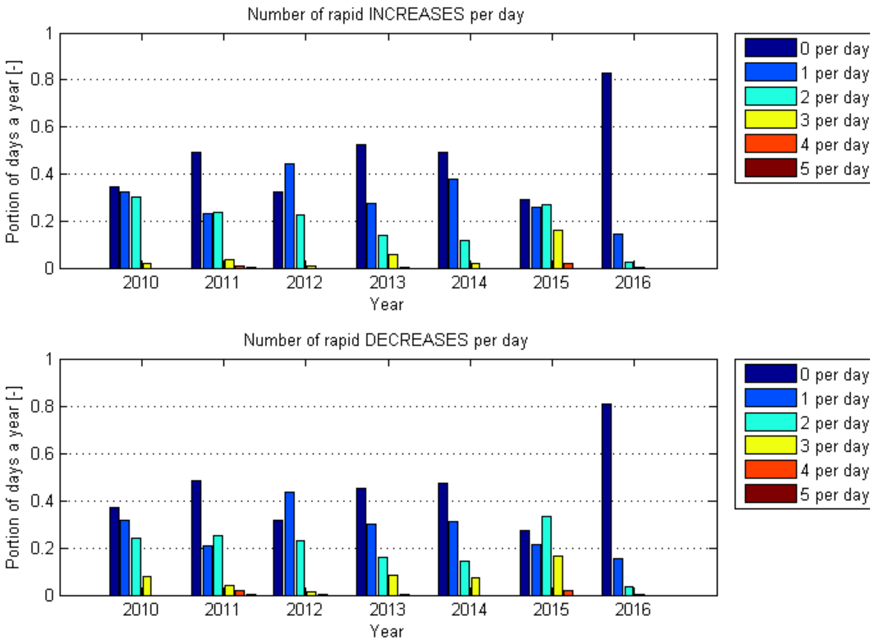

Figure 25 – Number of rapid increases and rapid decreases per day.

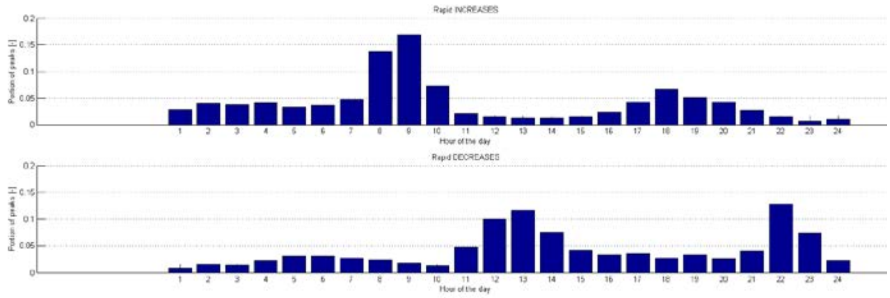

Figure 26 – Number of rapid increases and rapid decreases during the day.

According to Figure 26, most of the peaking events occur during daylight, 55% of rapid increases and 50% of rapid decreases. Along the year the peak events in darkness occur mainly in the autumn and winter season (Figure 28).

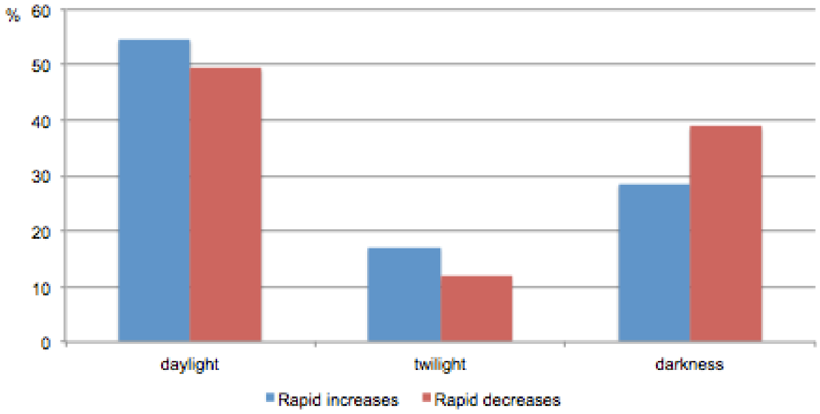

Figure 27 - Percentage of rapid increases and decreases according daylight conditions (daylight, twilight and darkness).

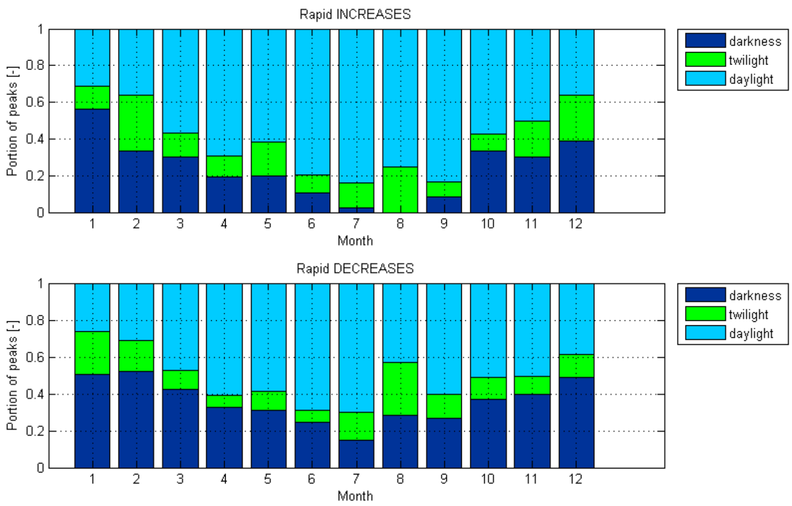

Figure 28 – Monthly distribution of rapid increases and rapid decreases according to light conditions, i.e. daylight, twilight and darkness.

The methodology proposed by Carolli *et al.* (2015) was applied to the subdaily flow series from 1st October 2010 to 30th September 2016 at the river reach downstream Bragado HPP. Two scenarios were considered: the actual scenario considering the flow regulation due to Bragado HPP operation and the pristine situation, prior to the existence of the HPP, i.e. the natural flow regime.

The natural flow series was used to calculate the limits TR_{HP1} and TR_{HP2} in order to characterize the level of impact of the HPP. The results of Carolli et al. (2015) parameters are shown at Table 8. The highest value concerning the modified flow regime for HP1 was 3.4 (2011/12) and for HP2 was 0.56 $m^3/s/h$ (2014/15). Considering the natural flow, both parameters HP1 and HP2 show values close to zero.

Therefore, Avelames River was classified as class 3, except for the 2015/16 year during which it was classified as class 2a. Concerning the natural flow regime, the classification of Carolli et al. (2015) returned class 1 for all the years analysed Table 8.

Table 9 – Values of Hydropeaking Impact (HP) and Threshold (TR) values for Avelames River downstream Bragado HPP considering the Carolli et al. (2015) methodology.

River reach	Hydrologic year	HP1 [-]	TR_{HP1} [-]	HP2 [$m^3/s/h$]	TR_{HP2} [$m^3/s/h$]	Class
Modified (with Bragado HPP)	2010/2011	1.65	0.45	0.30	0.07	3
	2011/2012	3.40	0.43	0.49	0.03	3
	2012/2013	1.03	0.63	0.27	0.09	3
	2013/2014	1.52	0.82	0.33	0.13	3
	2014/2015	1.62	0.49	0.56	0.06	3
	2015/2016	0.89	0.75	0.10	0.13	2a
Natural (without Bragado HPP)	2010/2011	0.09	0.45	0.01	0.07	1
	2011/2012	0.08	0.43	0.00	0.03	1
	2012/2013	0.11	0.63	0.01	0.09	1
	2013/2014	0.13	0.82	0.01	0.13	1
	2014/2015	0.08	0.49	0.00	0.06	1
	2015/2016	0.12	0.75	0.01	0.13	1

3.3.2.2. Fish location

Fish were tagged with the PIT-tag on the 16 and 17 of May 2018 (Figure 28).

Figure 29 – a) Electrofishing at the upstream river reach ; b) fish measurements: weight and length.

In total, 104 individuals were individually marked with the PIT tags, 79 in the downstream river reach and 25 in the upstream river reach (Table 9).

Table 10 – Fish PITtagged in the upstream and downstream river reach

River reach	Fish species	N	% of the total tagged fish	Total weight (g)	Total length (cm)
Upstream Bragado weir	*Squalius alburnoides*	7	28	6.1±2.8	8.3±1.4
	Squalius ~~pyrenaicus~~carolitertii	17	68	8.0±8.6	8.2±2.0
	Pseudochondrostoma duriense	1	4	6	8.6
Downstream Bragado HPP	*Squalius alburnoides*	8	10	3.9±1.8	7.2±0.7
	Squalius ~~pyrenaicus~~carolitertii	18	23	15.6±13.6	10.2±2.2
	Pseudochondrostoma duriense	53	67	7.0±5.3	8.5±1.7

After marking the fish caught with the PIT-tag we have initially returned to the river to check fish positions two more times, roughly corresponding to the seasons late spring and late summer. At the upstream river reach, that was planned to act as the reference site, we were unable to find any of the marked fish. Probably due to external factors, like the existence of a quarry upstream the river that was compromising the water quality.

Consequently, we have concentrated the study focus on the

~~The~~ river reach downstream Bragado HPP, that was surveyed six times in each season. One person, carrying the portable antenna moved upstream in a zigzag pattern (Figure 29). The antenna was immediately above the water for low depths and immersed in the water for higher depths. The operator moved discretely to avoid fish displacement.

Figure 29~~30~~ – Operator carrying the portable antenna looking for marked fish on the a) upstream river reach, and b) downstream river reach.

Each time a fish was recorded a sound was emitted by the receiver and another operator recorded: i) the fish code number associated to the PIT-tag; ii) the fish location, with a dual-frequency GNSS receiver (Trimble R2), iii) water depth, iv) velocity, v) bed substrate, and vi) the fish location regarding the water release from the HPP, either upstream or downstream. The first rough results are shown at Table 10.

Table 11 – Number of fish records for each species in late spring and late summer.

Species	Late Spring						Late Summer					
	1	2	3	4	5	6	1	2	3	4	5	6
Squalius alburnoides	1	2	1	-	-	-	-	-	-	-	-	-
Squalius ~~pyrenaicus~~carolitertii	3	3	4	7	4	5	3	2	5	4	4	3
Pseudochondrostoma duriense	4	3	4	7	5	9	3	5	8	11	8	6
Total	8	8	9	14	9	14	6	7	13	15	12	9

On average, we have detected 10 individuals in each survey. The same fish was detected in different surveys occupying distinct habitats. Generally, fishes were recorded immediately upstream the water release from Bragado HPP and in the centre of the river channel - *c.* 50 m downstream the water release. In total, from the 79 PIT-tagged fish, 36 individuals were recorded; a few were recorded several times. From all the individuals detected, 2 were *S. alburnoides*, 13 were *S. pyrenaicus*, and 21 were *P. duriense* (Figure 31). The rank of the different species was the same for the marked and detected fish (Table 11 and Figure 3~~1~~0). Nevertheless, proportionally less S. *alburnoides* and *P. duriense* were detected, whereas the opposite was observed with *S. carolitertii*.

Table 12 - Proportion of each species in the specimens marked and detected in the downstream reach.

Species	% of the tagged specimens	% of the detected specimens
Squalius alburnoides	10	3
Squalius ~~pyrenaicus~~carolitertii	23	38
Pseudochondrostoma duriense	67	59

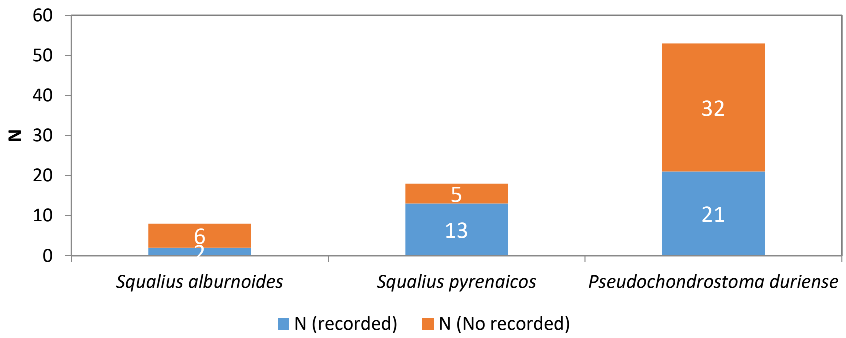

Figure 30~~0~~ – Number of fish individuals detected and not detected by species during the seasons late Spring and late Summer.

During the late spring campaign, we have also identified potential spawning grounds grouped in 14 areas along the downstream river reach.

Another set of field campaigns is planned for the spring of 2019, including the marking of additional specimens and their tracking.

Commented [FGodinho4]: continua a falar-se assim, ou diz-se que foi feita?

3.3.2.3. *Macroinvertebrates*

The samples were collected from the downstream river reach on the 19 of June of 2018. We have collected 3 drift samples (Figure 32): one upstream and two downstream of the HPP release. Also, 2 “kick” samples were collected, one upstream and the other was collected downstream of the HPP (Figure 3~~2~~1).

Figure 31~~1~~ – Macroinvertebrates sampling

The results for the samples of macroinvertebrates are presented in Table 12, for the “kick” samples, and in Table 13, for the drift samples.

Table 13 – Macroinvertebrate present in the “kick“ samples

Taxa	Upstream	Downstream
Boyeria irene	3	1
Calopteryx virgo	0	1
Onychogomphus uncatus	5	24
Cordulegaster boltonii	0	1
Hydropsyche siltalai	1	1
Helicopsyche helicifex	0	2
Polycentropus corniger	9	0
Psychomyia ctenophora	5	0
Setodes	8	12
Ephemerella ignita	3	7
Baetis	48	15
Habroleptoides	13	7
Habrophlebia	11	0
Caenis	36	3
Ecdyonurus	16	0
Aphelocheirus aestivalis	3	4
Gerris	32	0
Leuctra	16	9
Perla	1	0
Hydraena	1	0
Ochthebius	1	0
Limnebius	1	1
Oulimnius (adult)	7	7
Oulimnius (larvae)	2	5

Taxa	Upstream	Downstream
Elmis (adult)	1	0
Elmis (larvae)	1	3
Esolus (adult)	1	0
Limnius (larvae)	1	1
Sialis fuliginosa	5	0
Atherix	3	2
Athrichops crassipes	0	1
Simulium	1	4
Ceratopogoninae	0	4
Chironomini	14	3
Tanytarsini	0	2
Orthocladiinae	29	12
Tanypodinae	17	5
Tabanidae	0	3
Tipula	0	1
Anthomyiidae	0	1
Dolichopodidae	0	1
Eriopterini	0	1
Hydracarina	8	1
Potamopyrgus antipodarum	138	1376
Ancylus fluviatilis	1	8
Pisidium	1	1
Radix	0	1
Erpobdella	0	5
Dugesia	1	0
Lumbriculidae	1	2

Table 14 – Macroinvertebrates present in the drift samples

Taxa	Upstream	Downstream left	Downstream right
Boyeria irene	2	1	0
Calopteryx virgo	0	1	0
Onychogomphus uncatus	0	0	1
Tinodes waeneri	1	0	0
Setodes	0	0	1
Ephemerella ignita	2	2	1
Baetis	6	6	2
Habrophlebia	0	3	0
Caenis	0	3	0
Aphelocheirus aestivalis	0	2	1
Gerris	4	0	1
Protonemura	0	2	1
Leuctra	0	2	1
Anacaena	1	0	0
Hydraena	1	0	0

Taxa	Upstream	Downstream left	Downstream right
Oulimnius adult	2	0	0
Elmis larvae	1	2	1
Esolus larvae	0	0	1
Bidessus	0	0	1
Simulium	12	2	78
Ceratopogoninae	0	0	1
Chironomini	3	0	1
Tanytarsini	2	1	3
Orthocladiinae	7	3	8
Tanypodinae	0	1	1
Hydracarina	1	3	7
Potamopyrgus antipodarum	1	141	34
Ancylus fluviatilis	1	1	3
Erpobdella	0	0	2
Lumbriculidae	0	1	0

The abundance of the invasive mud snail (*Potamopyrgus antipodarum*) stands out in comparison with the other identified invertebrate taxa (Table 12 and Table 13). In a Mediterranean climate stream system, this invasive species interacted and competed with other grazing invertebrates, had a greater grazing impact in comparison with native snail species and reduced the survival of amphibian tadpoles (Bennett *et al.* 2015). Bennett et al. (2015) suggest that flow regulation could enhance their effects, by eliminating high flows that reduce their population sizes. However, this is likely not the case of Bragado, because the weir storage is small and does not affect the magnitude of the flood events.

4. References

Bennett, D.M., Dudley, T.L., Cooper, S.D. & Sweet, S.S. 2015. Ecology of the invasive New Zealand mud snail, Potamopyrgus antipodarum (Hydrobiidae), in a mediterranean-climate stream system. *Hydrobiologia*, **746**, 375–399, https://doi.org/10.1007/s10750-014-2136-6.

Brown, R.S., Cooke, S.J., Anderson, W.G. & McKinley, R.S. 1999. Evidence to Challenge the "2% Rule" for Biotelemetry. *North American Journal of Fisheries Management*, **19**, 867–871, https://doi.org/10.1577/1548-8675(1999)019<0867:ETCTRF>2.0.CO;2.

Cabral, M.J.J., Almeida, J., et al. 2005. *Livro Vermelho Dos Vertebrados de Portugal*. MJ, C., J, A., et al. (eds). Lisboa, Instituto da Conservação da Natureza.

Carolli, M., Vanzo, D., Siviglia, A., Zolezzi, G., Bruno, M.C. & Alfredsen, K. 2015. A simple procedure for the assessment of hydropeaking flow alterations applied to several European streams. *Aquatic Sciences*, **77**, 639–653, https://doi.org/10.1007/s00027-015-0408-5.

CEN. 2003. Water quality: sampling of fish with electricity. European Standard EN 14011:2003.

Cortes, R.M., Calçada Duarte, J.P. & Monzon, A. 1990. Habitat and fish populations parameters in a headstream. *SCIENTIA gerundensis*, 53–60.

Cucherousset, J., Roussel, J.-M., Keeler, R., Cunjak, R.A. & Stump, R. 2005. The Use of Two New Portable 12-mm PIT Tag Detectors to Track Small Fish in Shallow Streams. *North American Journal of Fisheries Management*, **25**, 270–274, https://doi.org/10.1577/M04-053.1.

Doadrio. 2001. *Atlas y Libro Rojo de Los Peces Continentales de España*. Doadrio, I. (ed.). Dirección General de Conservación de la Naturaléza Museo Nacional de Ciencias Naturales.

Ferreira, M.T., Pinheiro, A.N., et al. 2000. *Avaliação Da Eficácia Das Passagens Para Peixes de Pequenos Aproveitamentos Hidroeléctricos e Suas Alterações Ecológicas Sobre a Ictiofauna Fluvial.* Lisboa.

Filipe, A.F. 2004. *Revisão Do Livro Vermelho Dos Vertebrados de Portugal: Peixes Dulciaquícolas e Migradores. Relatório Final.*

Godinho, F.N., Ferreira, M.T. & Portugal e Castro, M.I. 1998. Fish assemblage composition in relation to environmental gradients in Portuguese reservoirs. *Aquatic Living Resources*, **11**, 325–334, https://doi.org/10.1016/S0990-7440(98)80003-X.

Godinho, F.N., Pinheiro, P.J., Oliveira, J.M. & Azedo, R. 2014. Responses of intermittent stream fish assemblages to irrigation development. *River Research and Applications*, **30**, 1248–1256, https://doi.org/10.1002/rra.2748.

INAG. 2001. *Plano de Bacia Hidrográfica Do Rio Douro. Hidrorumo, Hidro4, Procesl e Prosistemas.*

INAG. 2008. Manual para a avaliação biológica da qualidade da água em sistemas fluviais segundo a Directiva Quadro da Água: Protocolo de amostragem e análise para a fauna piscícola.

Kelly, B.B., Cary, J.B., Smith, A.D., Pregler, K.C., Kim, S. & Kanno, Y. 2017. Detection Efficiency of a Portable PIT Antenna for Two Small-Bodied Fishes in a Piedmont Stream. *North American Journal of Fisheries Management*, **37**, 1362–1369, https://doi.org/10.1080/02755947.2017.1388886.

Lencastre, A. 1993. *Hidráulica Geral*. LNEC.

Madeira, J.M. 2002. *Inventariação Da Ictiofauna Presente Na Bacia Hidrográfica Do Rio Douro*.

Oliveira, J.M., Santos, J.M., Teixeira, A., Fereira, M.T., Pinheiro, P.J., Geraldes, A. & Bochechas, J. 2007. *Avaliação Da Qualidade Ecológica de Rios Portugueses: Programa Nacional de Monitorização de Recursos Piscícolas de Águas Interiores.* Lisboa.

Portela, M. 2014. *Da Regionalização de Informação Hidromédrica Ao Dimensionamento de Albufeiras de Regularização e à Análise de Incertezas*.

Reyjol, Y., Hugueny, B., et al. 2007. Patterns in species richness and endemism of European freshwater fish. *Global Ecology and Biogeography*, **16**, 65–75, https://doi.org/10.1111/j.1466-8238.2006.00264.x.

Rodriguez-Ruiz, A. & Granado-Lorencio, C. 1992. Spawning period and migration of three species of cyprinids in a stream with Mediterranean regimen (SW Spain). *Journal of Fish Biology*, 545–556, https://doi.org/10.1111/j.1095-8649.1992.tb02682.x.

Santos, J.M., Godinho, F., Ferreira, M.T. & Cortes, R. 2004. The organisation of fish assemblages in the regulated Lima basin, Northern Portugal. *Limnologica*, **34**, 224–235, https://doi.org/10.1016/S0075-9511(04)80047-1.

Sauterleute, J.F. & Charmasson, J. 2014. A computational tool for the characterisation of rapid fl uctuations in fl ow and stage in rivers caused by hydropeaking. *Environmental Modelling & Software*, **55**, 266–278, https://doi.org/10.1016/j.envsoft.2014.02.004.

StatSoft. 2000. STATISTICA for Windows.

Winter, J.D. 1983. Underwater biotelemetry. *In*: Nielsen, L. A. & Johnsen, D. L. (eds) *Fisheries Techniques*. Bethesda, Maryland, American Fisheries Society, 371–395.